Potential for the Mike Basin Model to Support Innovative Water Resource Management in South Africa

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ABSTRACT

In excess of 50% of South Africa's catchments are deemed to be over-allocated (NWRS, First Edition 2004). With few economically viable augmentation options available, water resource managers are exploring all viable options to improve the efficiency with which water is used and to minimize avoidable losses and wastage.

In this document two issues are discussed which are believed to be vital to promote improved water use efficiency, including:

- Meaningful dialogue, supported by appropriated decision support tools (computer models), is required between water resource managers and stakeholders in order to evaluate various options to improve the efficiency with which water is used in catchments.
- New innovative institutional arrangements need to be introduced. The Fractional Water Allocation and Capacity Sharing (FWA-CS) institutional arrangement is introduced, and compared to the existing Priority-based River and Reservoir Operating Rule (PRROR) institutional arrangement.

The Mike Basin model is discussed in the light of these requirements.

Keywords: Water use efficiency, institutional arrangements, stakeholder participation, Mike Basin model

1 INTRODUCTION

The focus of Integrated Water Resources Planning (IWRP) and Management (IWRM) in South Africa has shifted from solving water scarcity problems with supply side solutions to investigating water management options to improve reliability of supply and increase water availability. One could say we are moving away from the water resource development era into the water resources management era. The transition is related to the fact that in general South Africa's water resources are reaching a state of maturity in that the most economically viable development options have already been explored[1] (Perkins and Seetal, 2004). The focus has thus shifted away from the development of new augmentation schemes, to the improved management of existing water resources[2].

The movement away from a Riparian Rights system to an Administration System which requires all forms of water use to be licensed unless exempt, has created an enabling environment for improved water resource management. The licensing system provides water resource managers with a framework with which they can identify where, when, how and by whom water is being used. Applications for water use entitlements can be turned down and existing uses reduced under certain circumstances, as stipulated in the 1998 National Water Act. Given the fact that a number of catchments in South Africa have reached a state of being fully developed (NWRS, First Edition 2004), there is a strong drive for water to be used more efficiently, with the hope of liberating water via the introduction of Water Conservation and Demand Management (WCDM) initiatives. Added to this is the requirement in the NWA (1998) to make water management more participatory with stakeholders actively becoming involved in the management of water resources.

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[1] As the demand for water grows, the value of water will increase, and new augmentation options will become economically viable. The result is that water augmentation options that are currently economically unviable may well become viable in the future.
[2] There will still be a need for new dams and inter-basin transfers (and other forms of augmentation) to be developed, however these will probably only be initiated once it has been ascertained all viable WCDM have been explored and adopted.

In this paper the authors focus on two key aspects which they believe could assist with improving water use efficiency and losses associated with water management in catchments throughout South Africa:

- The first aspect is to enable the conversation that needs to take place between water resource managers and stakeholders so they can evaluate various strategies and options to improve the efficiency with which water is used and managed in catchments. To encourage this dialogue which involves complex issues and tradeoffs a decision support framework that promotes understanding and confidence is required. The authors believe that the Mike Basin model is an appropriate tool to use to promote this dialogue.
- The second is the introduction of innovative institutional arrangements to induce improved levels of water use efficiency. The Fractional Water Allocation and Capacity Sharing (FWA-CS) institutional arrangement is described, and compared to the existing Priority-based River and Reservoir Operating Rule (PRROR) institutional arrangement.

2 IMPROVING THE DIALOGUE BETWEEN WATER RESOURCE MANAGERS AND STAKEHOLDERS

A founding principle of the National Water Act (1998) is that decision making is devolved to local stakeholders, who are to be duly represented on the respective Catchment Management Agencies. It is thus important to create an enabling environment within which stakeholders can participate meaningfully in decision making associated with the management of water resources. The following aspects will need to be addressed to facilitate this interaction;

- The stakeholders will need to have a better understanding of water resources management. The stakeholders do not need to be water resource managers but need to understand how catchments are operated and what impacts various operating rules and management decisions will have on them as individuals and the community of water users. Operating rules, such as priority of water use, restriction levels, the triggering of management actions such as inter-basin transfers, will need to be understood by stakeholders and the risks associated with these decisions communicated explicitly.
- There are a large number of complex interactions between the natural and anthropologically modified resources in a particular catchment and an assessment of the impacts that various decisions have individuals and the resource are difficult to quantify without the aid of a computer model (or set of computer models). Models are in effect simplified representations of reality. They can be used to promote a better understanding of complex systems, and can be used to assess "what if" scenarios.
- While, the physics and mathematics defining the many interactions in a catchment can be quite complicated needing powerful numerical solvers, the actual process of changing inputs and generating and communicating outputs can be made simple and understandable allowing all stakeholders to engage in conversations associated with catchment management decisions.
- Stakeholders will require an understanding of the situational assessment of water resources, as well as details of possible interventions, and the possible/probably consequences of such interventions to be communicated to them effectively.

The Mike Basin model is one framework which could be used to facilitate such interactions. Among other aspects it is possible to use the model to perform the following types of analyses.

- Situational analyses,
- Scenario formulation and testing, and
- Real time operation and decision support

Features that enable Mike Basin to promote dialogue between water resource managers and stakeholders include:

- The model is integrated in GIS. The linkage between water resources and water users is explicitly defined and spatially accurate promoting understanding by stakeholders.
- The graphical user interfaces and reports are well presented, and the look-and-feel of the model facilitates the transfer of information to stakeholders. The stakeholders can interrogate the model for detailed, individually defined outputs, or summarized outputs showing overall resource capacities.
- The attributes of water supply and demand nodes can easily be interrogated. Users can interrogate:
    - Demand profiles
    - Operating rules
    - Infrastructure characteristics (e.g. Height, volume area relationships for dams)
- The model can operate on various time steps, e.g. daily, weekly, and monthly. This is important as the most appropriate time step can be selected to best represent the operational activities in the catchment.
- The model has a sound database, and the newer version of Mike Basin is integrated with the Arc-hydro database.

- The model can be accessed via the Command Object Module (COM) interface, thus allowing tailored routines to be included. This allows for the following types of analysis to be undertaken (DHI, 2003):

    - Rapid sensitivity analysis through (many) Monte-Carlo simulations
    - Rapid execution and analysis of multiple scenarios
    - Post-processing of results (using Excel's statistics functions or other)
    - Optimization of any kind through Excel's Solver tool ('Data' menu) or any other COM-supporting optimization software
    - Implementation of any mechanism besides MIKE BASIN's standard allocation algorithms (e.g., operation of inter-related multiple reservoirs).
    - Dynamic simulation control (step-wise simulation, hotstart from any previous time step, or even iteration within a time step)
    - Easy creation of simple Excel user interfaces to site-specific MIKE BASIN models (that can be executed also by non-GIS users)
    - In South Africa these customization have been used for accounting for the following elements:

        - Output routines have been developed to provide users and water resource managers with a reliability of supply estimates
        - An IFR module has been integrated into the model
        - An irrigation module has been integrated into the model (which allows water use demands and return flows to be more appropriated simulated than is currently done)

- The GIS can be used for other applications, which may be required to facilitate the assessment of the beneficial use of water (which can vary spatially in a catchment).
- The Mike Basin model can interface with a Water Quality module, and has a rudimentary ground water module.
- Mike Basin can also interface with other software to access near-real time data, and can thus with some development be used for operational purposes (e.g. water audits).
- The model is well supported, and continually being developed and kept in line with advances in software engineering.
- The model has a large client base which enables users to benefit from applications around the globe

2.1 Some examples of the use of Mike Basin in South Africa

The Mike Basin model has been set up on a number of catchments in South Africa and the COM interface has been used to provide custom outputs for users in these areas. The example below shows the configuration of Mike Basin in the Letaba catchment showing the graphical user interface being used in the ArcView 3.2 environment. The latest version due for release this month is incorporated on the ArcGis 9 platform. The interface allows for the following aspects quick setup using GUIs to provide changes locally relevant changes (Figure 2.1) of the model and interrogation of information time series input and output for specific nodes (Figure 2.2).

The model outputs have also been manipulated to provide locally information such as probabilistic reservoir trajectories associated with specific sets of operating rules (Figure 2.3) and probability plots for local users (Figure 2.4). This enables user to identify their own reliability of supply and communicates the specific impact that an operating rule has on individual users. This information can be produced for short term plots or for longer term planning action. The types of plots that are produced can be seen by the yield diagram shown for the Mhlathuze catchment (Figure 2.5) which enables users to identify the historical system yield. Added to this individual long term reliability of supply estimates can be calculated for each of the different users on the system.

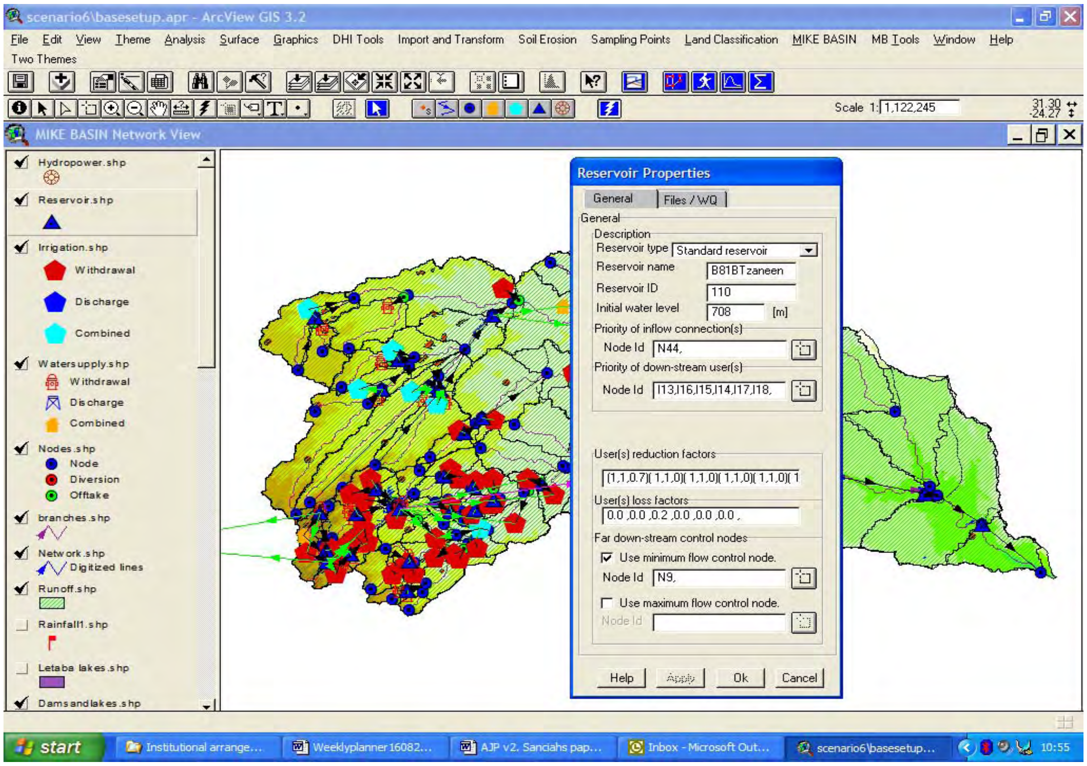

Figure 2.1: Mike Basin setup for the Letaba catchment showing GUI for reservoir input for Tzaneen Dam.

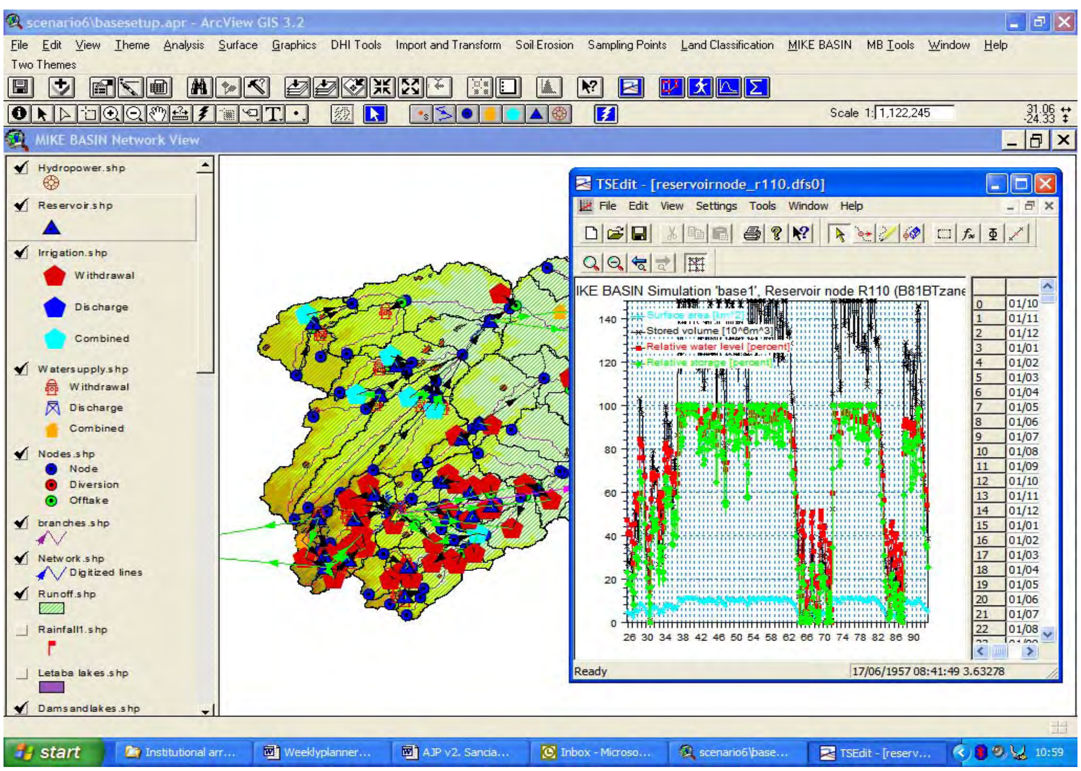

Figure 2.2: Mike Basin for the Letaba Catchment showing the standard time series editor with outputs of reservoir trajectories for Tzaneen dam

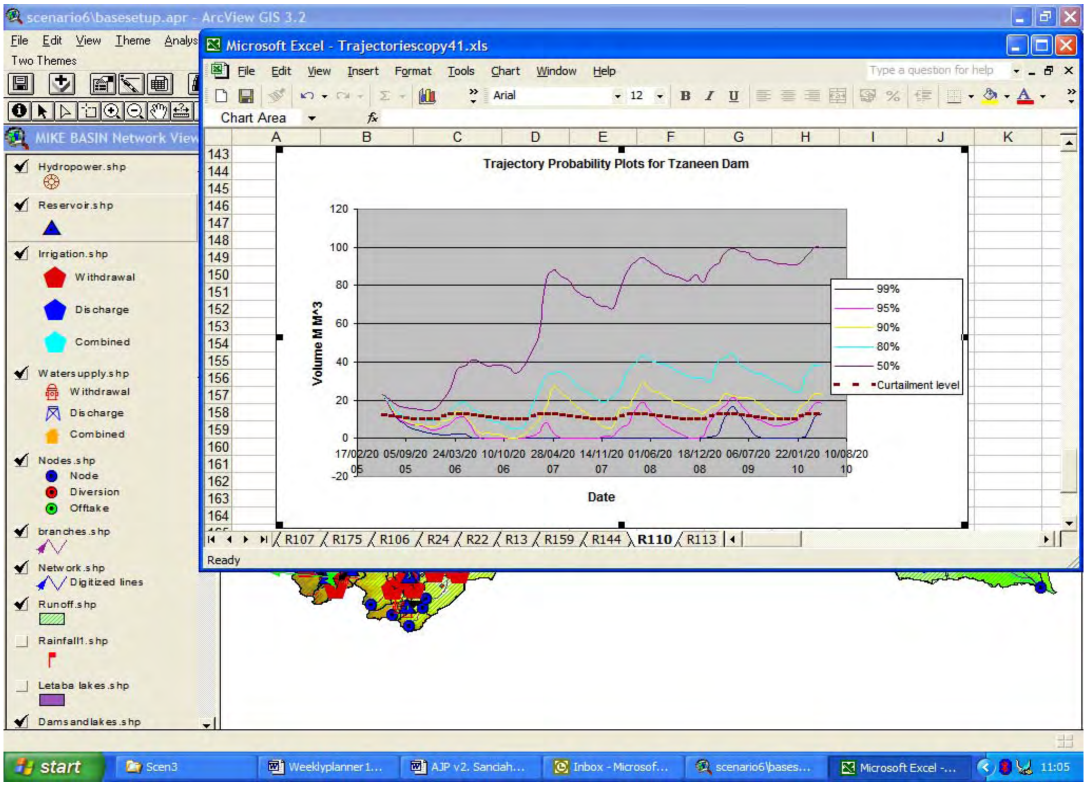

Figure 2.3: Reservoir trajectory probability trajectory plots generated by Mike Basin in Excel through the COM interface for Tzaneen Dam on the Letaba catchment, with a fluctuating reservoir rule curtailment super imposed

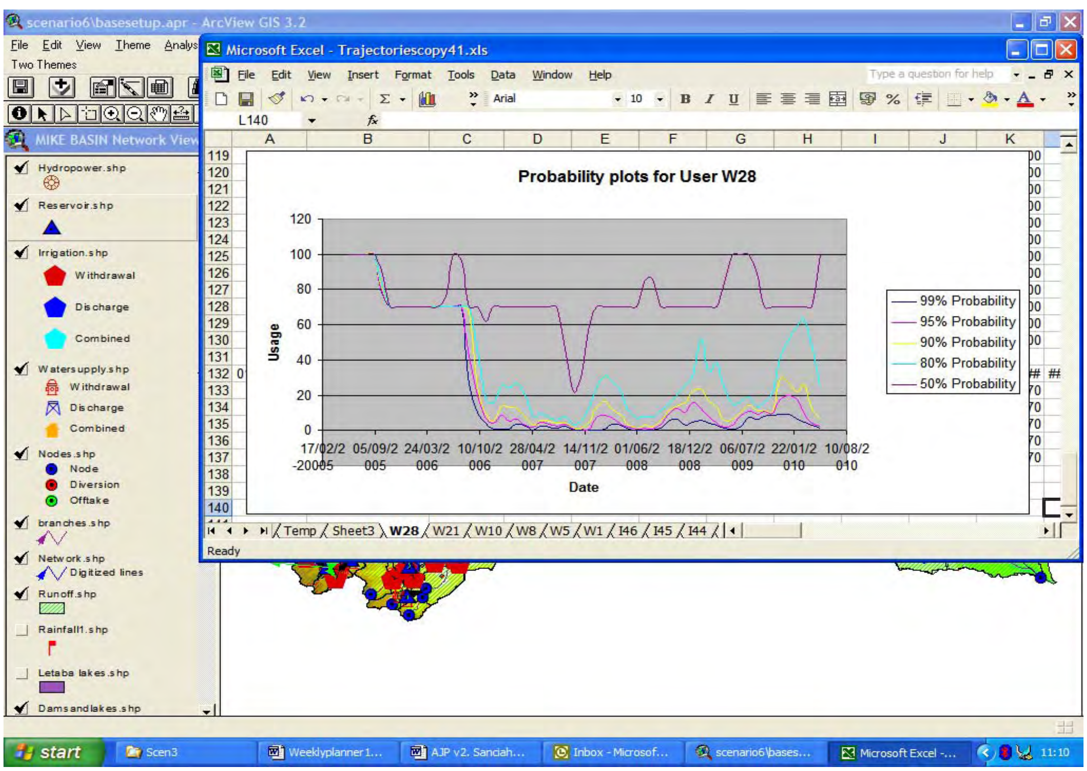

Figure 2.4: User probability plots for Polokwane showing giving an indication of exceedance probability for a specific operating rule.

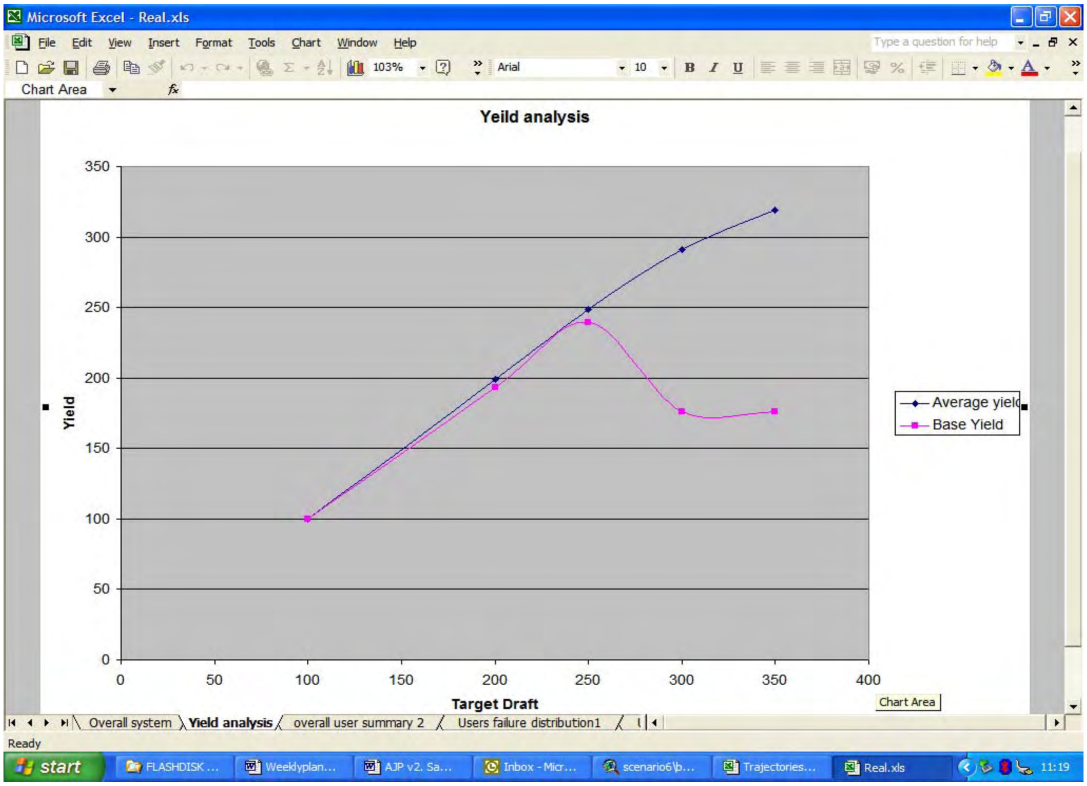

Figure 2.5: Yield analysis for the Mhlatuze catchment showing the base and average yield and the historical firm yield point

3 THE SEARCH FOR INNOVATIVE INSTITUTIONAL ARRANGEMENTS

An Institutional Arrangement (IA) can be defined as 'sets of working rules that are used to determine who is eligible to make decisions in some arena, and what actions are allowed or constrained. The rules describe what procedures must be followed, what information must or must not be provided and what payoffs will be assigned to affected individuals' (Ostrom, 1990). This definition leads to the need to define "organisation", which is often confused with an institution. According to Backeberg, (pers comm.), institutions are defined as the set of ordered relationships between people which determine their rights, exposure to the rights of others, privileges and obligations. This is distinctly different from organisations which are the cooperation between people which is conscious, deliberate and purposeful. Therefore the 1998 National Water Act is an institution and Water User Associations and Catchment Management Agencies are organisations. In theory and practice organisations cannot exist without the existence of institutions. Therefore to put it simply, organisations are the players and institutions are the rules of the game.

The 1998 National Water Act has identified eleven different types of water use, which need to be licensed for the water use to be authorised. The term "institutional arrangement" in this context refers to the conditions (privileges and obligations) attached to the licenses. The privileges relate to how much water may be used by a given water user, when and where at it may be used, and what it may be used for. The institutional arrangements define how water resources are operated and how water is apportioned amongst competing water users. For example, the institutional arrangement may define:

- The priority with which competing water users are to receive water, and
- The level (severity) of water restrictions that will be imposed on the various water users during periods of water shortage.

Obligations include, amongst others, the water use charges that must be paid by the holder of the water use entitlement/s.

The 1998 National Water Act is referred to as a framework act, which allows, and in fact promotes the adoption of measures that promote the equitable efficient and sustainable use of water resources. The institutional arrangement generally applied in South Africa currently is referred to as a Priority-based River and Reservoir Operating Rule (PRROR) institutional arrangement, and is described below. An innovative institutional arrangement, referred to as a Fractional Allocation and Capacity Sharing (FWA-CS) institutional arrangement is introduced after describing the PRROR IA.

3.1 The Priority-based River and Reservoir Operating Rule institutional arrangement

The currently adopted water apportionment system is for the purposes of this document referred to as the Priority-based River and Reservoir Operating Rule (PRROR) system (no need for reference). As the name suggests, the system discerns between priorities given to different types of authorised water use, while reservoir and river operating rules govern the water restrictions faced by the water users under different conditions of water availability. In the PRROR system, the catchment is managed as a single system, and licenses are issued against the system. Water users are not provided with details of the resources they hold entitlements against, even though these are reflected in computer models such as the Water Resources Yield Model and Water Resources Planning Model. Water managers are tasked to apportion water within the catchment to the most appropriate users, using a Priority-based Reservoir and River Operating System. The operating rules refer to water restriction rules imposed on water uses. The entitlement is specified as a volume (usually per annum). With respect to irrigation related entitlements, it is possible for other conditions to be added to the entitlement which limit the area that can be planted to a given crop (Perkins, pers comm.) Use is made of the Water Resources Yield Model (WRYM) to capture the water resources, authorised water users and their linkages and priorities to the resources, as well as the restriction rules of the authorised water users.

Restriction rules are often based on water levels of storage facilities (e.g. dam water levels), and the nature of water users. The reason for this is that; (i) the rule is simple to understand, and easy to enforce, (ii) a high level of control can be exercised over dams (i.e. by the water control officer, who is in charge of releases from the dam), and (iii) dams are generally a vital source of water during periods of water shortage. Table 3.1 below illustrates how restriction levels of the PRROR system vary depending on (i) the nature of the water user, and (ii) the level of water in the dam. The table is just an illustration of restriction levels. The restriction levels may vary from one dam to another, however the general trend is for the irrigation sector to receive higher levels of water restriction that the other sectors. The restriction levels are an effective, but not necessarily and efficiency inducing operating rule that gives effect to different levels of assurance to the various water use sectors.

Table 3.1: Varying restriction levels during periods of water shortage

DAM LEVEL	IRRIGATOR	DOMESTIC USER	INDUSTRIAL USER
>= 75%	No restriction	No restriction	No restriction
>= 50% & < 75%	Less 25%	No restriction	No restriction
>= 25% & < 50%	Less 50%	Less 10%	No restriction
>= 15% & < 25%	Less 75%	Less 25%	No restriction
< 15%	Less 90%	Less 30%	Less 10%

Just as the imposition of water use restrictions may be triggered by pre-defined dam levels, so too can they be levelled on the availability of water in streams where no dams are present. Often, due to the inability of abstraction pumps to regulate the flow rate at which water is pumped at, rules are put in place to accommodate for this. Examples are given where certain abstractors on the left bank of the river are allowed to abstract on designated days of the week, while the right bank may irrigate on alternate days (Examples by whom?). Auditing (compliance monitoring) is also made easier given such a rule, as it will then be easy to identify users who are abstracting on the wrong day.

A few disadvantages of the Priority-based River and Reservoir Operating Rule (PRROR) institutional arrangement are:

- A use-it-or-lose-it principle is applied to water use from large dams. If water users do adopt more efficient water use technologies, or don’t use their water (for whatever reason), the entitlement to this water is lost, and other users may use this water during periods of water shortage. The irrigation sector is currently the largest water user in South Africa, and has the lowest assurance of supply (inferring that it has the lowest priority level to use water, and is faced with the highest level of restriction). The implication of this is that as water becomes scarcer, the irrigators have an incentive to use as much water as they can within their entitlements, otherwise they stand to lose it once restrictions set in.
- The PRROR is difficult to operationalise, and to audit in that information is required regarding:
    - Details of the respective water resources in a catchment, with an understanding of how the resources are linked with one another (if at all),
    - The volume of water available in the respective water resources of the catchment,
    - Details of all authorised water users and their location in the catchment, including their priority status, and details of restriction rules associated with the users, and
    - Details of the access the various authorised water users have to the respective water resources

- All of this information is required to work out how to apportion the available water amongst the competing users (as per the "rules of the game"). Even though the WRYM is able to apportion water as required, the model operates on a monthly time step, which may be too coarse a time step for local requirements.
- The limited involvement of stakeholders in the management of the system may detract from the ability to and interest of stakeholders to "community police" water use in the catchment.
- The different levels of assurance of supply between sectors, brought about by different levels of priority and restriction rules, complicate water trading between sectors.

3.2 The Fractional Water Allocation and Capacity Sharing Institutional Arrangement

In the FWA-CS system, water resources are divided into storage (dams in particular) and flow resources, and entitlements are issued against these respectively (Dudley, 1990). The term FWA-CS is an acronym for Fractional Water Allocation (FWA - which is the allocation against the flow resources) and Capacity Sharing (CS – which is the allocation against the capacity of dam capacity).

Figure 3.1. below illustrates diagrammatically how the FWA-CS system operates. The diagram illustrates how the flow into the dam has been apportioned, with fractions (proportions) of the flow being allocated amongst water users. The capacity of the dam is also divided into proportions. The proportions of the dam capacity held by a user do not have to be the same as the flow proportions held by the same user. The user can vary these to tailor the assurance of supply that he desires.

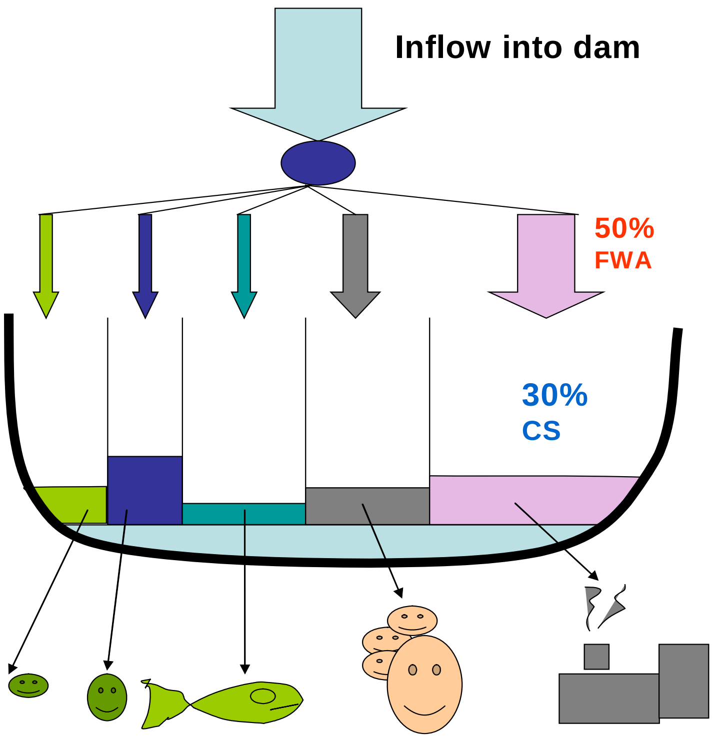

Figure 3.1: A graphical conceptual illustration of the Fractional Water Allocation and Capacity Sharing Institutional Arrangement

From an operational point of view, water users will operate their share of dam capacity like a bank account. Inflows will increase the account, whereas releases, pro-rata evaporation and pro-rata seepage losses will be deducted from the account. The account can be operated on a relevant time-step, e.g. weekly, fort-nightly, monthly etc.

The advantages of the FWA-CS system are:

- Water users are given an incentive to use water efficiently, particularly as the water level in dams starts dropping (and the economic scarcity value of the water starts rising A more detailed discussion of the mechanics of the incentive is given below.
- Previously disadvantaged communities can receive favourable lease options to shares of the dam which can then be sub-let to existing users. This can be done temporarily to help these communities build up capital reserves which may be required to use the water beneficially.

- DWAF can manage releases for the Reserve, while other water users can tailor their own assurances of supply independently (within their financial means). DWAF and/or consultants could provide the water users with planning and operational advice to ensure that water is used judiciously.
- Neighbouring countries can lease capacity shares of South African dams, and thereby cater for their own water releases. This may be a viable water related NEPAD (New Partnership for Africa's Development) initiative.
- The FWA-CS system promotes water trading, in that water use entitlements are very clearly specified, and the water user/s can quickly and easily establish who holds water rights, from where, and what the banked water levels are where dams exist.
- This option was the preferred option of stakeholders and was successfully adopted in the Mazowe catchment in Zimbabwe (Doertenbach, 1998), and is being applied in Australia (Ryan et al, 2000).
- A form of water banking was successfully (albeit temporarily) adopted in the Mhlathuze (Richards Bay) catchment in South Africa during the heat of a drought. Unfortunately this has not been formally documented.
- The water banking option is in harmony with the underlying principles of the 1998 National Water Act. In fact it could be argued that because it provides incentives to efficient water use, it is more in harmony with the 1998 National Water Act than the traditional volumetric and assurance of supply approach to water allocation.
- Software has been developed by the Danish Hydraulic Institute, in the form of Mike Basin, which can accommodate FWA-CS in an easy to understand format based on a GIS (arc-view) platform.
- With the FWA-CS framework it is possible to calculate and communicate entitlements to users at fine temporal scales (even as fine a time scale as daily), and audits can be performed at the time scale at which the entitlements are calculated at. The advantage of this is that while water is abundant calculations can be performed at relatively course time steps (e.g. monthly), however in times of water scarcity the scale can be increased to daily or weekly.

A few disadvantages of the FWA-CS system are:

- The initial configuration of catchments into allocation nodes against which Fractional Water Allocations are specified, as well as the process of initially allocating fractions (of dams and allocation nodes) to users will be a challenging undertaking. However, once done, the system should be simple to operate.
- Instrumentation and a relatively high level of management will be required to operate the FWA-CS system. However, the counter to this is that a higher level of management and monitoring instrumentation will be required irrespective of the system adopted.
- As FWA-CS is a new concept, and is largely untested in South Africa, there will be a resistance by many people, who may prefer to use established tried-and-tested methods.
- The FWA-CS institutional arrangement may not be suitable for all catchments in South Africa. In general, the larger the catchment, the more difficult it will be to apply this methodology.

4 DISCUSSION AND CONCLUSIONS

There is a need to improve water management in South Africa from both the operational and planning perspective. Added to this is the requirement of more decentralized water management where water users and other interested stakeholders need to become actively involved in water management and planning decisions. There is a clear need to get users to participate in the catchment management dialogue. The catchment management dialogue and the more participated management could be encouraged by focusing on the following key issues:

- Changing institutional arrangements that encourage more participative management by placing the control of the resource more into the users' hands. These institutional arrangements in general have the potential to improve water use efficiencies and reduce losses through improved management.
- Decision support systems that can effectively communicate with water resource stakeholders showing the consequences of management actions from a local perspective as well as from the general resource perspective.

The Mike Basin software allows users to explore unique institutional arrangements and can facilitate the communication process with the stakeholders. Added to this it can be implemented as a real time solution with catchment management decisions being made at a suitable time and spatial scale resulting improved water resources management. It is from this perspective that the model should be investigated in more detail for use in Water Management in South Africa.

Unique institutional arrangements should be investigated in more detail with the appropriate software as they have the advantage of improving stakeholder participation in catchment management decisions. These types of arrangements could well lead to better use of water and a more equitable allocation of the resource which could be used sustainably to the benefit of all stakeholders in South Africa.

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